Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies

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Abstract

The efficiency of unilateral climate policies may be hampered by carbon leakage and competitiveness losses. A widely discussed policy option to reduce leakage and protect competitiveness of heavy industries is to impose border carbon adjustments (BCAs). The estimation of carbon leakage as well as the assessment of different policy options led to a substantial body of literature in energy-economic modeling.

In order to give a quantitative overview on the most recent research of the topic, we conduct a meta-analysis on 25 studies, altogether providing 310 estimates of carbon leakage ratio according to different assumptions and models. The typical range of carbon leakage estimates are from 5% to 25% (mean 14%) without policy and from -5% to 15% (mean 6%) with BCAs.

A meta-regression analysis is performed to further investigate the impact of different assumptions on the leakage estimates. The decrease of the leakage ratio with the size of the coalition is confirmed and quantified. Among the BCAs options, the extension of BCAs to all sectors and the inclusion of export rebates are the most efficient features in the meta-regression model to reduce the leakage ratio. All other parameters being constant, BCAs reduce leakage ratio by 6 percentage points.

1. Introduction

International climate agreements are likely to remain subglobal in the years to come: the global climate architecture is shifting from a UNFCCC-led top-down regime to a bottom-up approach (Rayner, 2010). Differences in abatement

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targets among countries may lead to two distinct but interrelated issues: carbon leakage and competitiveness losses, especially among Energy Intensive Trade Exposed (EITE) sectors, such as cement, steel or aluminium (Dröge, 2009). Indeed, the asymmetry of carbon costs between regions may induce a shift of production of carbon intensive products from carbon-constrained countries to less carbon-constrained countries. As carbon dioxyde is a global pollutant, i.e. the geographic location of emissions has no influence on its environmental impacts, this carbon leakage would reduce the environmental effectiveness of the climate policies. Moreover, these production losses in heavy industries would also damage the economy and involve job destructions.

Carbon leakage and competitiveness issues have been one of the main arguments against the implementation of ambitious climate policies. A growing body of academic literature has been developed in the recent years to quantify the impacts of uneven climate policies and to find the best policy measures to counteract them. Among them, border carbon adjustments (BCAs), which consist in taxing products at the border on their carbon content, are widely discussed. Their consistency with the World Trade Organization (WTO) as well as their political consequences remain highly contentious among legal experts: they could constitute an incentive to join the climate coalition or trigger a trade war because of green protectionism suspicions.

Ex post econometrical studies have not revealed so far any evidence of carbon leakage (Reinaud, 2008; Ellerman et al., 2010; Quirion, 2011; Sartor, 2013) predicted in analytical models (Fischer and Fox, 2012; Jakob et al., 2013; Hoel, 1996; Markusen, 1975). *Ex ante* modeling are dominated by computable general equilibrium (CGE) models (Böhringer et al., 2012a) but there are also some sectoral partial equilibrium models (Mathiesen and Maestad, 2004; Monjon and Quirion, 2011b). Some literature reviews have been published recently on the subject (Branger and Quirion, 2013; Zhang, 2012; Quirion, 2010; Dröge, 2009; Gerlagh and Kuik, 2007) but to our knowledge no quantitative meta-analysis has been conducted on this topic.

Meta-analysis is a method developed to provide a summary of empirical results from different studies and test hypotheses regarding the determinants of these estimates (Nelson and Kennedy, 2009). It has been extensively used in medical research. The first meta-analysis in economics can be traced back to Stanley and Jarrell (1989). In the field of environmental and resource economics, the majority of meta-analyses summarizes the results of different nonmarket valuation studies (Van Houtven et al., 2007; Brander and Koetse, 2011; Barrio and Loureiro, 2010; Ojea and Loureiro, 2011; Richardson and Loomis, 2009). Closer to our subject, one can cite two studies on marginal abatement costs to mitigate climate change, one for all sectors (Kuik et al., 2009) and the other specific to agriculture (Vermont and De Cara, 2010). An extensive review of meta-analysis methods in environmental economics is given in Nelson and Kennedy (Nelson and Kennedy, 2009).

In this article, we conduct a meta-analysis on 25 studies dating from 2004 to 2012, altogether providing 310 estimates of carbon leakage ratios according to different assumptions and models. The typical range of carbon leakage estimates is from 5% to 25% (mean 14%) without policy and from -5% to 15% (mean 6%) with BCAs. We conduct a meta-regression analysis to further investigate the impact of different assumptions on carbon leakage estimates. Impact of key model parameters, such as Armington elasticities, and policy features such as linking carbon markets or extending pricing to all greenhouse gases sources can be highlighted. We find that, all other parameters being constant, BCAs implementation reduces the leakage ratio by 6 percentage points.

The remainder of this paper is structured as follow. Section 2 describes the database and section 3 provides some descriptive statistics. The meta-regression model is explained in section 4 and results are discussed in section 5. Section 6 concludes.

2. Database description

Many articles and working papers deal with carbon leakage and competitiveness issues but only some of them are models giving *ex ante* numerical estimates. The body of literature regarding these issues also comprises *ex post* econometrical analyses, analytical models and political or juridical studies (Cosbey et al., 2012; Ismer and Neuhoff, 2007; Monjon and Quirion, 2011b). The first criterion to be part of our sample was to provide numerical estimations of carbon leakage with a model. The second criterion was, since the purpose of this paper is to investigate the impact of border carbon adjustments on leakage, to include BCAs in the scenarios. Thirdly, we discarded old studies (before 2004) to focus on the recent literature.

To constitute our sample, we searched for studies in standard search engines (Web of Science, Google Scholar) and cross references with keywords "carbon leakage" and "border carbon adjustments". The research was completed in December 2012. Our sample is made of 25 studies dating from 2004 to 2012, most of them (14) are part of the recent Energy Economics Special Issue. Some are grey literature (MIT working paper, World Bank working paper, etc), others are published in energy economics and environmental economics journals (Energy Economics, Energy Policy, the Energy Journal, Energy Policy, Climate Policy etc). The majority are computable general equilibrium (CGE) models which rely on the GTAP database (except for one), the others are sectoral or multi-sectoral partial equilibrium models. The number of carbon leakage estimates per study varies from 2 (Weitzel et al., 2012) to 54 (Alexeeva-Talebi et al., 2012a), with a mean of 12.6.

The studied effect-size in the meta-regression analysis is the leakage-to-reduction ratio or leakage ratio,

$$l = \frac{\triangle E_{NonCOA}}{-\triangle E_{COA}}$$

where $\triangle E_{COA}$ is the emissions variation in the climate coalition between the climate policy scenario and the counterfactual business-as-usual scenario, and $\triangle E_{nonCOA}$ the emissions variation in the rest of the world. Its common use

Figure 1: Leakage ratio in selected studies (mean, minimum and maximal values with or without BCAs), ranked by mean value without BCAs

Figure 2: Leakage ratio reduction in case of Border Carbon Adjustment (same ranking as in figure 1)

avoids us to make approximate conversions between studies. In other words all studies calculate the same thing, which is necessary in a meta-analysis as a "synthesis requires the ability to define a common concept to be measured"(Smith and Pattanayak, 2002)).

In the majority of the cases results were available on tables, but sometimes they were taken from graphs or derived from own calculation like in Mattoo et al. (2009).

3. Descriptive Statistics

3.1. First sight

Figure 1 presents ranges of leakage ratio estimates for the 25 studies (mean, minimum and maximal values with or without BCAs). Leakage ratio estimates range from 2% to 41% without BCAs and from -41% to 27% with BCAs. Eight studies find negative values of leakage ratio in case of BCAs, with three studies (Mathiesen and Maestad, 2004; McKibbin et al., 2008; Lanzi et al., 2012) finding values below -15%. Internal variations (within one study) of leakage ratio estimates range from almost null (Alexeeva-Talebi et al., 2012b) to relatively high (Mathiesen and Maestad, 2004; Bednar-Friedl et al., 2012; Ghosh et al., 2012) depending on the scenarios and models.

Comparing scenarios by pair (with and without BCAs, all the other parameters being constant), we can observe that in all cases, BCAs led to a reduction of the leakage ratio[1]. These results are in contrast with (Jakob et al., 2013) who found that BCAs could increase the leakage ratio[2]. For each pair, we calculate the leakage ratio reduction in percentage points (defined as $LeakageRatioReduction = LeakageRatio_{NoBCAs} - LeakageRatio_{BCAs}$). In the majority of the cases, the leakage ratio reduction due to BCAs stands between 1 and 15 percentage points, but there are some outliers above 30 percentage points, where BCAs actually generates negative leakage ratios (McKibbin et al., 2008; Mathiesen and Maestad, 2004).

[1]In figure 1, for FF2012 (Fischer and Fox, 2012), the mean with BCAs is higher than with no BCAs, but the "equivalent" BCAs scenarios corresponds to the highest value of leakage ratio of the no BCAs scenario (Europe only abating).

[2]In this paper, under certain conditions, if in non-coalition countries, the carbon intensity of exports ("clean" sector) is higher than those of local production ("dirty" sector), a reallocation of production induced by BCAs from "clean" to "dirty" sector would increase emissions in non-coalition countries and then leakage ratio on a global scale

Apart from carbon leakage, competitiveness losses in energy-intensive industries constitutes the other component of the climate trade nexus. Though extensively used in the public debate, the notion of competitiveness remains ambiguous (Alexeeva-Talebi et al., 2012b). Some authors consider that this notion is meaningless at the national level (Krugman, 1994). At the sectoral level, it may refer to "ability to sell" or "ability to earn". In CGE models, competitiveness is most of the time implicitly defined as "ability to sell" and measured by gross output. In our sample, 17 of the 25 studies show results of output change for industries. Based on GTAP sectors, EITE sectors often regroups refined goods, chemical products, non-metallic minerals, iron and steel industry and non-ferrous metals (although sometimes refined goods is aside). Some studies present only disaggregated results by sectors, and not the output change for EITE sectors as a whole. In this case, we use the average of the output of iron and steel and non-metallic minerals sectors (or average of cement and iron and steel) as a proxy for EITE sectors[3].

The output change of EITE sectors varies from -0.1% to -16% without BCAs and from +2.2% to -15.5% with BCAs. There is a clear dichotomy between CGE models where output loss range is 0%-3% (except for Alexeeva-Talebi 2012 (b) and Ghosh et al. 2012 where it is a bit more (around 3%-7%)) and sectoral partial equilibrium models where output loss range is 8%-15%. In all cases, BCAs reduce the output loss among EITE industries[4] and in five cases (Peterson and Schleich, 2007; Alexeeva-Talebi et al., 2012b; Kuik and Hofkes, 2010; Mattoo et al., 2009; Ghosh et al., 2012), the output variation of EITE industries is even positive.

The welfare (or in some studies GDP) variation of the abating coalition ranges from -1.58% to 0.02% without BCAs and from -0.9% to 0.40% with BCAs (the environmental impact is never taken into account in the welfare estimation[5]). Though BCAs improve welfare of coalition countries compared to a no BCAs scenario, they most of the time do not reestablish a "neutral" situation (e.g a variation near 0%). The welfare variation is still negative after BCAs, because the consumers of the coalition pay higher prices in EITE sectors' products. This improvement of welfare in coalition countries goes hand in hand with a degradation of welfare in non-coalition countries. BCAs have big distributionnal impacts: they transfer a part of the burden to the non-coalition countries (Böhringer et al., 2012c). In the studies that report it (Böhringer et al., 2012c; Lanzi et al., 2012; Mattoo et al., 2009), *global* welfare is decreasing with BCAs.

[3]For the only two studies where output changes were available both by sector and for EITE sectors as a whole (Lanzi et al., 2012; Ghosh et al., 2012), it was a correct proxy. Iron and Steel (resp. Non-Metallic Minerals) being a bit less (resp. more) impacted than EITE as a whole

[4]However in the CASE model (Monjon and Quirion, 2011a,b), cement output is more reduced in the presence of BCAs

[5]In the Energy Economics special issue, leakage is endogenously compensated by a higher abatement to assure a same environmental impact in all scenarios in order to compare welfare variations

Figure 3: Output change of EITE industries in selected studies (ranked by mean value without BCAs)

Figure 4: Welfare variation in abating coalition (ranked by mean value without BCAs)

3.2. Merging studies

Gathering all the estimates of carbon leakage in the 25 studies, we compute kernel density estimations for the estimates accross all studies. As the number of estimates varies greatly (from 2 to 54) across studies, we consider two ways of merging results, the "scenarios equality" method and the "articles equality" method. In the "scenarios equality" method, we add all estimates regardless of the article they are from. Then an article with N estimates "weights" $N/2$ times more in the final distribution than an article with only two estimates. In the "articles equality" method however, weights are put on estimates to assure that each article "weights" the same in the final distribution[6]. By this process the distribution of results with the "articles equality" method is less smooth because there are artificially some accumulation in the distribution. However the distributions share the same shape with both results, especially for the leakage ratio and the output variation of EITE industries, which can be interpreted as a sign of the robustness of the results.

Both leakage ratio distribution and EITE output change distribution are bimodal. For leakage ratio without BCAs there is a concentration around 5% and another around 12%[7]. We can see that a leakage ratio above 100%, theoretically possible if the carbon content of products is higher outside the climate coalition is well out of the range of estimates in the literature. For EITE output variation there is a concentration at -2% and another one (more spread out) at -7%, which can be interpreted as the dichotomy between CGE models and PE models. The coalition welfare variation distribution is unimodal, with a mode of -0.6% without BCAs and -0.3% with BCAs.

One can easily visualize in figures 6 and 7 the impact of BCAs in reducing the leakage ratio, restoring some competitiveness and to a lesser extent improving coalition welfare with the left shift of the leakage ratio distribution and the right shifts of output change and coalition welfare change distributions.

[6] If N_k is the number of estimates in the article k, the weight for an estimate from article i is then $\frac{\max_k(N_k)}{N_i}$ (and the closest integer value for kernel estimate using Stata). In this case each article weights $\max_k(N_k)$ in the final distribution.

[7] Not a single estimate of leakage ratio is negative without BCAs, the negative part is an artifact in the kernel density estimation

Table 1: Selected studies

Name	Reference	Journal	Model Name	Model type	Main Database	Cluster	Obs[†]
Boh2012	(Böhringer et al., 2012a)	En Eco (SI)[1]	Several	CGE	GTAP 7.1	1	26 (14+12)
Gho2012	(Ghosh et al., 2012)	En Eco (SI)	EC-MS-MR	CGE	GTAP 7.1	7	18 (6+12)
AT2012	(Alexeeva-Talebi et al., 2012a)	En Eco (SI)	PACE	CGE	GTAP 7.1	2	54 (27+27)
Lan2012	(Lanzi et al., 2012)	En Eco (SI)	ENV-Linkages	CGE	GTAP 7.0	3	44 (20+24)
Boh2012-2	(Böhringer et al., 2012b)	En Eco (SI)	BCR	CGE	GTAP 7.1	8	18 (9+9)
BalR2012	(Balistreri and Rutherford, 2012)	En Eco (SI)	MINES	CGE	GTAP 7.0	13	10 (5+5)
Wei2012	(Weitzel et al., 2012)	En Eco (SI)	DART	CGE	GTAP 7.0	13	2 (1+1)
FF2012	(Fischer and Fox, 2012)	En Eco (SI)	GTAPinGAMS	CGE	GTAP 7.0	10	5 (4+1)
BB2012	(Boeters and Bollen, 2012)	En Eco (SI)	WorldScan	CGE	GTAP 7.0	14	9 (3+6)
Spr2012	(Springmann, 2012)	En Eco (SI)	CVO	CGE	GTAP 7.1	11	7 (4+3)
Car 2012	(Caron, 2012)	En Eco (SI)	CEPE	CGE	GTAP 7.0	11	8 (4+4)
Bed2012	(Bednar-Friedl et al., 2012) et al.	En Eco (SI)	WEG_CENTER	CGE	GTAP 7.0	4	24 (12+12)
Boh2012-3	(Böhringer et al., 2012c)	En Eco (SI)	SNOW	CGE	GTAP 7.1	12	10 (1+9)
Ant2012	(Antimiani et al., 2012)	En Eco (SI)	GTAP-E	CGE	GTAP 7.1	10	3 (1+2)
Mat2009	(Mattoo et al., 2009)	World Bank WP[2]	ENVISAGE	CGE	GTAP 7.0	9	6 (1+5)
McKW2009	(McKibbin et al., 2008)	Lowy Institute WP	G-Cubed	CGE	n.a	9	4 (2+2)
PS2007	(Peterson and Schleich, 2007)	ISI Working Paper	GTAP-E	CGE	GTAP 6.0	15	6 (2+4)
KH2010	(Kuik and Hofkes, 2010)	Energy Policy	GTAP-E	CGE	GTAP 6.0	10	3 (1+2)
Win2011	(Winchester et al., 2011)	MIT Working Paper	EPPA	CGE	GTAP 6.0	9	5 (1+4)
BabR2005	(Babiker, 2005)	The Energy Journal	No Name	CGE	GTAP 5.0	12	2 (1+1)
MM2004	(Mathiesen and Maestad, 2004)	The Energy Journal	SIM	PE		6	11 (9+2)
MQ2011-1	(Monjon and Quirion, 2011a)	Ecological Economics	CASE II	PE		5	20 (10+10)
DQ2005	(Demailly and Quirion, 2005)	OECD Report	CEMSIM-GEO	PE		6	3 (1+2)
DQ2008	(Demailly and Quirion, 2008)	Energy Economics	CASE I	PE		6	6 (3+3)
MQ2011-2	(Monjon and Quirion, 2011b)	Climate Policy	CASE II	PE		5	6 (2+4)

[†] The numbers in parenthesis detail the number of leakage ratio estimates without and with BCAs implementation
[1] Energy Economics Special Issue [2] WP=Working Paper

Figure 5: Leakage ratio (Kernel density estimates)

Figure 6: Output change of EITE industries (Kernel density estimates)

4. Meta-regression analysis

4.1. Methods

Meta-regression is widely used in meta-analysis as it is an interesting way to go beyond standard literature review, by combining numerical results from different studies in a statistical manner (Vermont and De Cara, 2010; Kuik et al., 2009; Horváthová, 2010). Guidelines on how meta-regression analysis of economics research should be conducted were recently published (Stanley et al., 2013). The guidelines were divided into three topics: research questions and effect size; research literature searching, compilation and coding; and meta-regression modeling issues.

The first topic is discussed in the introduction (general context of the research question and statement of the effect studied) and in the end of part 2 (how the effect size is measured by the leakage ratio, which is a common metric). The second topic is discussed in the beginning of part 2 (how the literature was searched and what are the criteria for study inclusion). Table 1 gives detailed information on the articles used in the meta-analysis. Stanley et al. (2013) encourage that two or more reviewers should code the relevant research. In this study, only the first author searched and coded the research literature.

In the rest of this part, we will detail the third topic (modeling issues). As recommended as good practice, we display descriptive statistics of the variables that are coded (see Table 7 in the appendix for the effect size e.g. the leakage ratio, and Table 2 for the regression variables). Publication bias is a major issue in meta-regression analysis. This form of sample selection bias occurs if primary studies with statistically weak or unusual results are less likely to be published (Nelson and Kennedy, 2009). For example, it has been widely recognized to exaggerate the effectiveness of pharmaceuticals (Doucouliagos and Stanley, 2009). Statistical techniques to take this bias into account exist (Stanley, 2005; Rothstein et al., 2006; Havranek, 2013) but they require standard errors of the estimates. We cannot apply these methods here since we deal with numerical studies (no statistical significancy is involved and then no standard errors are given with the results). It is highly likely that a publication bias also exists in the area of modeling studies: authors compare their results with those of the literature and are able to change the settings or calibration of their models to influence the results. Our best option to address this issue was to embrace as many studies as possible without artificially setting aside some of them, e.g. non peer-reviewed papers.

Another potential issue is the existence and the treatment of outlier observations (some estimates that are unrepresentative or overly influential). To discard outliers we first perform a robust estimation procedure using iteratively

Figure 7: Welfare variation (Kernel density estimates)

Figure 8: BCAs leakage reduction (in percentage points)

Huber weights[8] (Huber, 1964) and only keep estimates whose final weights are above a certain threshold (5%). Among the first original samples of 310, 144 and 166 values (for "All", "no BCAs" and "BCAs", see later), 16, 10 and 6 observations were dismissed (20 out of 25 articles have less than one discarded estimate). The fact that the articles with the more discarded estimates were the relatively old ones (Mathiesen and Maestad (2004), Babiker (2005) and Peterson and Schleich (2007)) suggests that the literature is converging (which could also reflect a publication bias...). Estimation of parameters without the treatment of outliers is given in the appendix as a sensitivity analysis. The reader can verify that the exclusion of outliers slightly improves the statistical significance of some coefficients without substantially affecting the results of the meta-regression analysis.

Finally, heteroskedasticity in effect size variance and non-independence of observations of the same primary studies due to within study dependence has long been recognized as a potential estimation problem for meta-regression (Nelson and Kennedy, 2009). Some authors favor the use of a "best-set" of estimates, meaning a single estimate per study (Stanley, 2001) but this shrinks dramatically the pool of estimates. In our case we used a Random Effect Multi-Level (REML) model with study identifiers as in Doucouliagos and Stanley (2009), to control for the potential dependence of estimates within a primary study. A second method, a "cluster-robust" OLS estimator[9], as in Kuik et al. (2009) and Vermont and De Cara (2010)), is used as a sensitivity analysis (see appendix). Some differences on the coefficient values exist but overall our findings are robust to the method employed.

4.2. The model

To investigate the sources of heterogeneity among the different carbon leakage estimates, we test three variations of the meta-regression model based on different samples: one for all leakage ratio estimates, one for estimates in the absence of BCAs and the last one for estimates in the presence of BCAs:

$$\begin{aligned} Leakage_{ij} = \quad & Const + \beta_1 GE_{ij} + \beta_2 Coasize_{ij} + \beta_3 Abatement_{ij} + \beta_4 Link_{ij} \\ & + \beta_5 GHG_{ij} + \beta_6 Armington_{ij} + \beta_7 BCAs_{ij} + u_{ij} \end{aligned}$$

[8]The Stata command that is used is rreg

[9]The observations are gathered in 15 clusters (see Table 1). Studies with many observations are the first clusters (with the exception of Monjon and Quirion (2011a) and Monjon and Quirion (2011b) which are merged because results are from the same model CASE II), then studies that share common features are gathered in same clusters (2 or 3 studies per cluster representing 10-15 observations).

$$\begin{aligned} Leakage_{NoBCAs,ij} = \quad & Const + \beta_1 GE_{ij} + \beta_2 Coasize_{ij} + \beta_3 Abatement_{ij} + \beta_4 Link_{ij} \\ & \beta_5 GHG_{ij} + \beta_6 Armington_{ij} + u_{ij} \end{aligned}$$

$$\begin{aligned} Leakage_{BCAs,ij} = \quad & Const + \beta_1 GE_{ij} + \beta_2 Coasize_{ij} + \beta_3 Abatement_{ij} + \beta_4 Link_{ij} \\ & + \beta_5 GHG_{ij} + \beta_6 Armington_{ij} + \beta_8 Exp_{ij} + \beta_9 Foreign_{ij} \\ & \beta_{10} AllSect_{ij} + \beta_{11} Indirect_{ij} + u_{ij} \end{aligned}$$

where $Leakage_{ij}$ is the i-th estimate of leakage ratio reported in the j-th study.

The choices of the variables in the models are driven by the scenarios and the available data in the studies, as well as the debates in the literature. The first variables are *GE* (a dummy variable set equal to 1 if the model is a CGE), *Coasize* (the size of the abating coalition in percentage of worldwide emissions[10]) and *Abatement* (the abatement target)[11]. Then we have two dummies related to scenarios *Link* (if permit trading is authorized between the different regions of the coalition[12]) and *GHG* (if all carbon sources, and not only CO2 are considered).

Armington elasticities, which are used to model international trade, are considered as a crucial parameter in leakage ratio estimates (Monjon and Quirion, 2011a; Alexeeva-Talebi et al., 2012a; Balistreri and Rutherford, 2012). Most of the time they were not explicitly displayed in the articles. However some studies made sensitivity analyses on this parameter (for example doubling or dividing in half the original values). In the meta-analysis, the *Armington* parameter is then, rather than a numerical value, an "almost dummy" linked with "high" (+1), "low" (-1), "very high" (+2) or "very low" (-2) Armington elasticities values[13] when sensitivity analysis were performed on these parameters. It would have been interesting to incorporate a parameter for the fossil fuel supply elasticity which is also recognized to be determinant in the leakage ratio estimations for the international fossil fuel channel (Light et al., 1999; Gerlagh and Kuik, 2007). However, because they were not available most of the time, it was decided not to take them into account in the meta-regression.

BCAs is a dummy which takes the value of 1 if BCAs are implemented. It is the central parameter of our study since we primarily investigate to what extent BCAs are efficient to reduce leakage. Four dummies detail the policy

[10] In the overwhelming majority of the articles, the coalitions were centered on Europe, in several cases enlarge to Annex 1 except Russia (A1xR) or A1xR plus China. Therefore no variable was considered to describe the coalition in itself (for example EU or US), but only its size in terms of worlwide emissions.

[11] The logarithm of *Coasize* and *Abatement* have been tried as variables without changing the statistical significancy of the results

[12] which supposes that the abating coalition is composed of more than one region in the model. For example if Europe is the abating coalition it is not considered that permit trading is allowed

[13] In Balistreri and Rutherford (2012) the Melitz structure (Melitz, 2003) is considered equivalent to "very high" Armington

features of the BCAs: *Exp* (if export rebates are part of the scheme), *Foreign* (if the adjustment is based on foreign specific emissions, instead of home specific emissions or best available technology), *AllSect* (if the adjustment concerns all sectors and not only EITE sectors), and *Indirect* (if indirect emissions are taken into account in the adjustment). Table 2 summarizes information about the regression variables.

5. Discussion of the results

Interpreting the results, one must bear in mind that, though meta-regression analysis is a powerful tool to incorporate all the sources of variability in a single model, one must interpret the results with caution. Indeed, the calculated coefficients depend not only on primary models, that made different assumptions, but also on the statistical variability of the parameters which is, except for the variable *BCAs*, far from being perfect. For example, *Abatement* is set at 20% for 61% of the cases and varies within three studies only (Böhringer et al., 2012a; McKibbin et al., 2008; Demailly and Quirion, 2008). *Indirect* is set at the value 1 for 91% of the cases and varies within two studies only (Böhringer et al., 2012c; Monjon and Quirion, 2011b). This aspect is unavoidable in a meta-regression analysis as we take already made studies and do not design the scenarios by ourselves. We still include these "poorly variable" variables in the regression, and interpret the coefficients in the light of this aspect, knowing that they may be biased or may not appear as statistically significant as they may have been.

The results of the meta-regresssion are visible Table 3. We recall that three estimations are performed: one for all the leakage ratio estimates, one for those in the absence of BCAs and one for those in the presence of BCAs. The quality of the estimations is assessed through the Wald χ^2 test and the LR (Likelihood Ratio) test that compares the results with the linear regression. The presence of within-study dependence is revealed by the Durbin-Watson test (computed after a simple OLS estimation), and the LR test confirms that the use of a REML estimation is appropriate.

The difference between CGE models and other models is statistically significant and is positive (except for the "no BCAs" sample). We find that, all other parameters being constant, the leakage ratio estimate is 9 percentage points higher in CGE models and 12 percentage points in the case of BCAs implementation, which is a noteworthy difference. The lack of non-CGE models estimates (non CGE models constitute only one fifth of the articles and even less in terms of leakage ratio estimates) remains an impediment for the statistical value of this coefficient. An explanation could be that CGE models include both channels of leakage ratio, the competitiveness channel and the international fossil fuel channel, which is recognized to predominate (Gerlagh and Kuik, 2007; Fischer and Fox, 2012; Weitzel et al., 2012) whereas partial equilibrium models only include the first one (except for Mathiesen and Maestad (2004)).

The coefficient for the coalition size is negative and very statistically significant. Changing the size of the coalition from Europe (15% of world's emissions in 2004) to Annex 1 plus China except Russia (71% of world's emissions in 2004)

Table 2: Meta-regression variables

Name	Variable type	Explanation	Summary statistics	Variability[1]	
GE	Dummy	1 if the model is a CGE	268 (87% of the cases)	Correct	0/20/5
Coasize	Percentage	Size of the abating coalition (percentage of worldwide emissions)	Mean 35% Mode: 15% (for 39% of the cases)	Good	9 - 8
Abatement	Percentage	Abatement target	Mean 19% Mode: 20% for 61% of the cases	Poor	4 - 8
Link	Dummy	Possibility to sell permits across the coalition	83 (27% of the cases)	Correct	2/11/12
GHG	Dummy	If carbon pricing is extended to all GHG sources	9 (3% of the cases)	Poor	2/23/0
Armington	5 values (-2/-1/0/1/2)	1 (resp. -1) corresponds to "Armington high" (resp. "Armington low"). 2 for "Melitz" or higher Armington than "Armington high"	31 for 1 and 37 for -1 (10% and 12% of the cases)	Correct	4 - 5
BCA	Dummy	1 if there is border carbon adjustments	167 (54% of the cases)	Very Good	25/0/0
Exp	Dummy	1 if export rebates are part of the scheme	146 (87% of the BCA cases)	Good	6/17/2
Foreign	Dummy	1 if the adjustment is based on foreign specific emissions (or average foreign). 0 if home (or BAT)	114 (68% of the BCA cases)	Good	8/9/8
Allsect	Dummy	1 if the adjustment concerns all sectors and not specifically Energy-intensive sectors	47 (28% of the BCA cases)	Good	4/6/15
Indirect	Dummy	1 if indirect emissions are taken into account in the adjustment	152 (91% of the BCA cases)	Poor	2/20/3

[1] For dummies, x/y/z means that the parameter takes both values 1 and 0 in x articles, 0 only in y articles and 1 only in z articles. For others, a-b means that the parameter takes more than two different values within a articles, and that there are b values taken by the parameter in total.

Table 3: Meta-regression results. REML estimation

	All	No BCAs	BCAs
GE	0.091	0.047	0.124
	(2.74)***	(1.60)	(4.27)***
Coasize	-0.214	-0.221	-0.147
	(12.12)***	(10.97)***	(5.94)***
Abatement	0.090	0.163	0.084
	(1.04)	(1.78)*	(0.69)
Link	0.003	-0.005	0.002
	(0.26)	(0.48)	(0.13)
GHG	-0.029	-0.014	-0.062
	(2.24)**	(1.04)	(2.82)***
Armington	0.019	0.033	0.003
	(4.68)***	(7.75)***	(0.51)
BCA	-0.063		
	(14.27)***		
Exp			-0.039
			(2.98)***
Foreign			-0.020
			(1.90)*
Allsect			-0.042
			(2.90)***
Indirect			-0.015
			(0.87)
N	294	134	160
Wald χ^2	$386.13^\dagger$	$192.61^\dagger$	$78.25^\dagger$
LR test	$220.50^\dagger$	$96.95^\dagger$	$42.02^\dagger$
DW test OLS	0.68	0.52	1.08

† $prob = 0.0000$

would involve in the model a decrease of leakage ratio of about 12 percentage points without BCAs and 8 percentage points with BCAs.

Theoretically, the bigger is the abatement, the higher is the leakage in absolute terms (tons of carbon emissions). As the leakage ratio is the leakage in absolute terms divided by the abatement and the latter increases as well, there is an indeterminacy about the relationship between the abatement and the leakage ratio. In the meta-regression model, the correlation is positive, but the statistical significancy is weak (a p-value below 0.1 is reached only for the no-BCAs sample), which may be attributable to the small variability of this parameter. In Alexeeva-Talebi et al. (2012b) (which was not included in our study because there was no BCAs), the correlation is negative (leakage of 32%, 29% and 27% for Europe abating respectively 10%, 20% and 30% of its emissions). In Böhringer et al. (2012b) however, the relationship is positive (leakage of 15.3%, 17.9% and 21% for Europe abating respectively 10%, 20% and 30% of its emissions).

Concerning the policy parameters, authorizing permit trading (linking) within the coalition is not statistically significant. In the two studies that change explicitly this parameter in the different scenarios (Lanzi et al., 2012; Springmann, 2012), permit trading diminishes leakage to a small extent. It is therefore the lack of variability *between studies* that may explain this non-significance (about half of the articles have permit trading in all their scenarios and the other half do not in all their scenarios).

Conversely, extending carbon pricing to all GHG sources is statistically significant, especially when BCAs are implemented (decreasing the leakage ratio by 6 percentage points). However the poor variability of this parameter diminishes the confidence we can grant to this econometric estimation (two articles study the coverage extension to all GHGs in one of their scenarios, but all the other articles only consider carbon emissions, i.e. there is no variability between studies).

The Armington parameter proves statistically significant (except for the "BCAs" sample) and is positive as expected. A higher value, meaning a more "flexible" international trade modeled, induces more impact of price differentiation across regions on trade flows, and therefore more leakage. In our meta-regression model, taking high values of Armington elasticities instead of low values would then lead to leakage ratio estimates about $2 \times 1.9 = 3.8$ percentage points higher.

With a very high p-value, we find that the BCA parameter is statistically significant and is negative. All other parameters being constant, BCAs implementation reduces the leakage ratio by 6 percentage points. This statistical finding fits the data in the descriptive statistics section (figure 8).

More specifically, among the BCAs options, export rebates and the inclusion of all sectors instead of only EITE sectors would have the most important impact (decrease of 4 percentage points of the leakage ratio for each), roughly the double than basing adjustment on foreign specific emissions instead of home specific emissions. In this meta-regression model it is not the politically and juridically risky option (foreign carbon content based adjustment) that would be the most efficient to reduce leakage but more an option with high administrative costs (adjustment to all sectors). The inclusion of indirect emissions is without surprise not statistically significant (there is very little statistical variability for this parameter). In the two studies where a change of this feature is included in the scenarios, it is proven to reduce leakage: in Böhringer et al. (2012c), from 0.5 to 2 percentage points, depending on the adjustment level, and in Monjon and Quirion (2011a), from 1.5 to 2 percentage points.

Meta-regression results can also be used to make out-of-sample predictions, which is called benefit transfer (Nelson and Kennedy, 2009; Van Houtven et al., 2007). This exercise is especially interesting for meta-analysis of empirical studies as they allow forecast for other locations or commodities which may save the employed resources to make additional surveys. Here we show as an example the results of leakage ratio estimations with the meta-regression analysis coefficients for different abating coalitions and policies (see Table 4). The estimated values of leakage ratio seem reasonable but the 95% confidence intervals are very wide.

6. Conclusion

A global climate policy is unlikely to be implemented in the years to come and the adoption of ambitious national or regional climate policies is hindered by claims of industry competitiveness losses and carbon leakage. Border Carbon Adjustment (BCAs) has been proposed to overcome these hurdles but its potential efficacy has been controversial. Moreover some authors argue that BCAs aims at protecting heavy industries competitiveness rather than at tackling leakage (Kuik and Hofkes, 2010) while other authors defend that BCAs implementation cannot be justified only for competitiveness motives (Cosbey et al., 2012). Finally, BCAs proposals differ by key design choices such as the inclusion of exports rebates, indirect (electricity-related) emissions, or the adjustment level, which can be the domestic or foreign average specific emissions, or best-available technologies. How BCAs performance would be impacted by these choices remains an open question.

To shed some light of these issues, we have gathered and analysed 310 estimates of carbon leakage and output loss in Energy-Intensive Trade-Exposed (EITE) sectors from 25 studies dating from 2004 to 2012. A meta-regression was conducted to capture the impact of different assumptions on the model results.

Across our studies, the leakage ratio ranges from 5% to 25% (mean 14%) without BCAs and from -5% to 15% (mean 6%) with BCAs. BCAs reduce the leakage ratio with robust statistical significance: all parameters being constant in the meta-regression analysis, the ratio drops by 6 percentage points with the implementation of BCAs. In most CGE models, some leakage remains after BCAs implementation, which is not the case with partial equilibrium (PE) models. The most likely explanation is that in CGE models, a part of leakage is due to the international fossil fuel price channel which is unaffected by BCAs, while most PE models do not feature this leakage channel.

Concerning output loss for EITE industries, results are in sharp contrast to results about leakage: CGE models predict loss in a range from 0% to 4%

(mean 2%) without BCAs while PE models foresee more than the double. BCAs corrects for the output loss in CGE models but less so in sectoral models. The explanation seems that in PE models, a higher output loss is due to a drop in demand for CO_2-intensive materials, loss which is mitigated by BCAs.

Further, the importance of the coalition size is statistically confirmed and quantified, as well as the impact of extending pricing to all greenhouse gases. The latter reduces the leakage ratio, and the smaller the abating coalition, the bigger the leakage ratio. This meta-analysis also confirms the importance of Armington elasticities in the leakage ratio estimation, a result crucial in terms of uncertainty analysis, which calls for more transparency and sensitivity analyses regarding these parameters in future studies.

The features of BCAs (coverage, level of adjustment, etc.) are of the highest importance for the WTO compatibility, feasibility, and political acceptability. The purpose of the meta-regression was also to assess their impact on competitiveness and leakage. In the meta-regression, the inclusion of all sectors and the presence of export rebates appear to be the two most efficient features to reduce leakage, followed by the adjustment level based on foreign carbon content. Yet one can guess, in the case of hypothetical BCAs implementation, that political and juridical aspects will be the more determinant and that only a “light” version (adjustment based on best available technologies, probably without the inclusion of indirect emissions) is likely to see the light of day.

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7. Appendix

7.1. Sensitivity analysis

Tables 5 and 6 present the different sensitivity analyses. Results including or excluding outliers are very similar. The noticeable differences are a slightly higher impact of BCAs for the model including outliers (BCAs diminish the leakage ratio by 7 percentage points instead of 6 percentage points) and less significant coefficient concerning the BCAs features.

Results with the OLS cluster-robust estimation and REML estimation are more diverging. In the OLS cluster-robust model, the impact of extending the coverage to all greenhouse gases is strongly bigger, the impact of the size of the coalition is twice less important and the value of the abatement coefficient is twice more important. Among the BCAs features, the coefficient measuring the effect of covering all sectors instead of only EITE sectors is also twice larger. Remarkably, the impact of BCAs on the leakage reduction is the same for the two models.

7.2. Summary statistics

Abating coalition	Europe		Annex 1 without Russia	
Target	15%	30%	15%	30%
No BCA (a)	19% [3%;33%]	21% [3%;38%]	12% [-5%;28%]	14% [5%;33%]
BCA light (b)	15% [-5%;34%]	16% [-8%;39%]	10% [-11%;31%]	11% [-13%;36%]
BCA strong (c)	9% [-16%;33%]	10% [-18%;38%]	4% [-22%;30%]	6% [-24%;35%]

(a) Estimation with the "All" model
(b) Estimation with the "BCAs" model. $AllSect = 1$ only
(c) Estimation with the "BCAs" model. $AllSect = 1$, $Foreign = 1$ and $Exp = 1$

Table 4: Benefit transfer: leakage ratio estimations by the meta-regression model

Table 5: Sensitivity analysis. Effect of the removal of outliers in the REML estimation

	All		No BCA		BCA	
	Original†	All Sample	Original†	All Sample	Original†	All Sample
GE	0.091	0.067	0.047	0.048	0.124	0.113
	(2.74)***	(1.58)	(1.60)	(1.19)	(4.27)***	(2.54)**
Coasize	-0.214	-0.192	-0.221	-0.256	-0.147	-0.124
	(12.12)***	(8.22)***	(10.97)***	(10.32)***	(5.94)***	(4.21)***
Abatement	0.090	0.158	0.163	0.111	0.084	0.203
	(1.04)	(1.36)	(1.78)*	(0.93)	(0.69)	(1.41)
Link	0.003	0.004	-0.005	-0.004	0.002	0.013
	(0.26)	(0.33)	(0.48)	(0.29)	(0.13)	(0.78)
GHG	-0.029	-0.026	-0.014	-0.010	-0.062	-0.062
	(2.24)**	(1.45)	(1.04)	(0.59)	(2.82)***	(2.35)**
Armington	0.019	0.019	0.033	0.032	0.003	0.003
	(4.68)***	(3.43)***	(7.75)***	(5.85)***	(0.51)	(0.40)
BCA	-0.063	-0.074				
	(14.27)***	(12.40)***				
Exp					-0.039	-0.040
					(2.98)***	(2.58)***
Foreign					-0.020	-0.020
					(1.90)*	(1.55)
Allsect					-0.042	-0.030
					(2.90)***	(1.75)*
Indirect					-0.015	-0.019
					(0.87)	(0.90)
N	294	310	134	140	160	166
Wald χ^2	386.13	238.64	192.61	147.17	78.25	42.97
LR test	220.50	216.05	96.95	121.06	42.02	62.14

† Some outliers are removed from the sample

Table 6: Sensitivity analysis. REML versus OLS cluster-robust estimation

	All		No BCA		BCA	
	REML	Cluster-robust OLS	REML	Cluster-robust OLS	REML	Cluster-robust OLS
GE	0.091	0.053	0.047	0.006	0.124	0.103
	(2.74)***	(1.60)	(1.60)	(0.21)	(4.27)***	(3.07)***
Coasize	-0.214	-0.107	-0.221	-0.067	-0.147	-0.105
	(12.12)***	(2.95)**	(10.97)***	(1.41)	(5.94)***	(2.69)**
Abatement	0.090	0.197	0.163	0.326	0.084	0.165
	(1.04)	(0.90)	(1.78)*	(2.22)**	(0.69)	(1.12)
Link	0.003	0.016	-0.005	0.020	0.002	0.008
	(0.26)	(0.77)	(0.48)	(1.23)	(0.13)	(0.40)
GHG	-0.029	-0.083	-0.014	-0.070	-0.062	-0.054
	(2.24)**	(5.01)***	(1.04)	(4.89)***	(2.82)***	(4.51)***
Armington	0.019	0.022	0.033	0.034	0.003	0.006
	(4.68)***	(3.36)***	(7.75)***	(4.36)***	(0.51)	(1.60)
BCA	-0.063	-0.065				
	(14.27)***	(6.63)***				
Exp					-0.039	-0.039
					(2.98)***	(2.03)*
Foreign					-0.020	-0.026
					(1.90)*	(2.31)**
Allsect					-0.042	-0.101
					(2.90)***	(4.01)***
Indirect					-0.015	0.001
					(0.87)	(0.08)
N	294	294	134	134	160	160
Wald χ^2	386.13		192.61		78.25	
LR test	220.50		96.95		42.02	
R^2		0.38		0.32		0.59

Table 7: Summary statistics for studies. Leakage Ratio

	No BCAs					BCAs				
	Mean	Range	Med	Std	Obs	Mean	Range	Med	Std	Obs
Boh2012	12.2%	(5.0% 23.9%)	12%	5%	15	7.5%	(2.0% 12.0%)	8%	3%	13
Gho2012	10.4%	(2.5% 26.2%)	8%	9%	6	0.8%	(-7.8% 9.5%)	7%	5%	12
AT2012	14.6%	(12.6% 18.0%)	14%	2%	27	10.0%	(9.8% 10.9%)	10%	0%	27
Lan2012	4.4%	(2.0% 9.1%)	4%	2%	20	-6.2%	(-21.0% 4.1%)	-2%	8%	24
Boh2012-2	10.5%	(4.0% 21%)	9%	6%	9	7.9%	(2.3% 19.4%)	5%	7%	9
BalR2012	17.9%	(12% 32.5%)	14%	9%	5	10.8%	(7.0% 19.0%)	9%	5%	5
Wei2012	19.5%	(19.5% 19.5%)	20%	0%	1	17.5%	(17.5% 17.5%)	18%	0%	1
FF2012	13.5%	(7.0% 23.0%)	12%	7%	4	19.0%	(19.0% 19.0%)	19%	0%	1
BB2012	19.5%	(10.0% 32.5%)	18%	9%	3	16.5%	(8.9% 26.9%)	15%	8%	6
Spr2012	14.2%	(13.6% 14.7%)	14%	1%	4	11.4%	(11.1% 11.6%)	11%	0%	3
Car 2012	16.0%	(15.0% 17.0%)	16%	1%	4	12.5%	(11.0% 13.0%)	13%	1%	4
Bed2012	22.4%	(14.3% 38.4%)	19%	9%	12	11.7%	(5.8% 23.0%)	10%	7%	12
Boh2012-3	17.0%	(17.0% 17.0%)	17%	0%	1	12.6%	(8.0% 16.0%)	14%	3%	9
Ant2012	13.5%	(13.5% 13.5%)	14%	0%	1	12.0%	(11.1% 12.9%)	12%	1%	2
Mat2009	4.0%	(4.0% 4.0%)	4%	0%	1	-1.8%	(-7.0% 1.0%)	0%	4%	5
McKW2009	7.5%	(4.0% 11.0%)	8%	5%	2	-22.5%	(-41.0% 22.5%)	-23%	26%	2
PS2007	26.5%	(25.0% 28.0%)	27%	2%	2	24.0%	(21.0% 27.0%)	24%	3%	4
KH2010	11.0%	(11.0% 11.0%)	11%	0%	1	9.0%	(8.0% 10.0%)	9%	1%	2
BabR2005	17.0%	(17.0% 17.0%)	17%	0%	1	16.0%	(16.0% 16.0%)	16%	0%	1
MM2004	24.2%	(0% 41%)	26%	11%	9	-4.5%	(-18.0% 9.0%)	-5%	19%	2
MQ2011-1	8.2%	(7.0% 11%)	8%	5%	10	-0.9%	(-4.2% 3.2%)	-1%	2%	10
DQ2005	13.0%	(13.0% 13.0%)	13%	0%	1	-1.0%	(-6.0% 4.0%)	-1%	7%	2
DQ2008	9.0%	(7.0% 11.0%)	9%	2%	3	-2.0%	(-2.0% 2.0%)	-2%	0%	3
MQ2011-2	10.4%	(10.4% 10.4%)	10%	0%	2	5.5%	(3.8% 7.1%)	2%	2%	4

Table 8: Summary statistics for studies. Output change for EITE industries

		No BCAs				BCAs				
	Sector	Mean	Range	Med	Std	Obs	Mean	Range	Med	Std
Boh2012	"EITE" (1)	-2.86%	(-5.20% -1.20%)	-2.8%	1.1%	13	-1.03%	(-3.00% -0.20%)	-0.9%	0.9%
Gho2012	"EITE" (1)	-5.66%	(-7.73% -3.58%)	-5.7%	2.4%	4	0.80%	(0.53%-0.94%)	0.9%	0.2%
AT2012	Own Average (7)	-1.83%	(-2.80% -1.00%)	-1.7%	0.9%	3	0.07%	(-0.10% 0.20%)	0.1%	0.2%
Lan2012	"EIT sectors" (2)	-2.17%	(-2.70% -1.90%)	-1.9%	0.5%	3	-0.45%	(-0.50% -0.30%)	-0.5%	0.1%
Boh2012-2	"EITE" (1)	-2.30%	(-4.95% -0.55%)	-2.2%	1.5%	9	-0.64%	(-1.29% -0.20%)	-0.6%	0.4%
Spr2012	"Energy-intensive goods (EIT) (3)	-2.01%	(-2.31% -1.77%)	-2.0%	2.2%	4	-0.27%	(-0.30% -0.23%)	-0.3%	0.0%
Car 2012	Own Average (6)	-3.20%	(-3.20% -3.20%)	-3.2%	0.0%	1				
Mat2009	"Energy-intensive Manufacturing" (4)	-2.30%	(-2.30% -2.30%)	-2.3%	0.0%	5	-0.08%	(-1.50% 2.20%)	-0.3%	1.4%
McKW2009	"Non durables" (5)	-0.15%	(-0.20% -0.10%)	-0.2%	0.1%	2	-0.25%	(-0.30% -0.20%)	-0.3%	0.1%
PS2007	Own Average (6)	-0.40%	(-0.40% -0.40%)	-0.4%	0.0%	4	0.20%	(0.10%-0.30%)	0.2%	0.1%
KH2010	Own Average (8)	-2.00%	(-2.00% -2.00%)	0%	0.0%	2	-0.05%	(-0.60% 0.50%)	-0.1%	0.8%
BabR2005	"Energy Intensive Goods" (3)	-1.20%	(-1.20% -1.20%)	-1.2%	0.0%	1	-0.30%	(-0.30% -0.30%)	-0.3%	0
MM2004	Steel (only sector)	-7.10%	(-7.10% -7.10%)	-7.1%	0.0%	2	-3.05%	(-4.40% -1.70%)	-3.1%	1.9%
MQ2011-1	Own Average (9)	-7.86%	(-7.86% -7.86%)	-7.9%	0.0%	1	-6.41%	(-6.90% -5.80%)	-6.4%	0.4%
DQ2005	Cement (only sector)	-7.50%	(-7.50% -7.50%)	-7.5%	0.0%	2	-2.50%	(-3.00% -2.00%)	-2.5%	0.7%
DQ2008	Own Average (9)	-11.67%	(-19.00% 5.00%)	-11.7%	7.0%	3	-4.33%	(-7.00% -2.00%)	-4.3%	2.5%
MQ2011-2	Own Average (9)	-7.47%	(-7.47% -7.47%)	-7.5%	0.0%	1	-5.47%	(-6.40% -5.00%)	-5.2%	0.7%

(1) Aggregation of 5 sectors (Refined goods, Chemical products, Non-metallic minerals, Iron and Steel industry, Non-ferrous metals)

(2) Aggregation of 4 sectors: same as (1) except no Refined goods

(3) 1 sector in the model. Probably same as (2)

(4) Specific sectors non specified

(5) One sector

(6) Iron and Steel and Non-Metallic Minerals

(7) Iron and Steel and Other Non-Metallic Minerals

(8) Steel and Mineral Products

(9) Steel and Cement

Table 9: Summary statistics for studies. Welfare variation for the abating coalition

		No BCAs					BCAs				
		Mean	Range	Med	Std	Obs	Mean	Range	Med	Std	Obs
Boh2012	GDP	-0.40%	(-0.40% -0.40%)	-0.40%	0.00%	1	-0.40%	(-0.32% -0.32%)	-0.32%	0.00%	1
Gho2012	Welfare	-0.66%	(-1.58% -0.28%)	-0.54%	0.47%	6	-0.66%	(-0.89% -0.21%)	-0.35%	0.23%	12
AT2012	Welfare	-0.35%	(-0.62% -0.21%)	-0.33%	0.13%	27	-0.35%	(-0.50% -0.25%)	-0.28%	0.11%	27
Lan2012	Welfare	-0.17%	(-0.35% -0.01%)	-0.18%	0.09%	23	-0.01%	(-0.12% 0.09%)	-0.02%	0.04%	24
BalR2012	Welfare	-0.43%	(-0.85% 0.02%)	-0.60%	0.41%	5	-0.43%	(-0.2% -0.40%)	0.01%	0.21%	5
Wei2012	Welfare	-0.50%	(-0.50% -0.50%)	-0.50%	0.00%	1	-0.50%	(-0.4% -0.40%)	-0.40%	0.00%	1
BB2012	Welfare	-0.74%	(-0.88% -0.54%)	-0.79%	0.18%	3	-0.74%	(-0.81% -0.50%)	-0.77%	0.15%	6
Spr2012	Welfare	-0.51%	(-0.54% -0.44%)	-0.54%	0.06%	3	-0.51%	(-0.42% -0.36%)	-0.38%	0.03%	3
Boh2012-3	Welfare	-0.69%	(-0.69% -0.69%)	-0.69%	0.00%	1	-0.69%	(-0.66% -0.42%)	-0.56%	0.08%	9
Mat2009	Welfare	-0.60%	(-0.60% -0.60%)	-0.60%	0.00%	1	-0.60%	(-0.50% -0.40%)	-0.50%	0.04%	5
McKW2009	GDP	-0.60%	(-0.60% -0.60%)	-0.60%	0.00%	2	-0.60%	(-0.60% -0.60%)	-0.60%	0.00%	2
Win2011	Welfare	-0.92%	(-0.92% -0.92%)	-0.92%	0.00%	1	-0.92%	(-0.90% -0.79%)	-0.87%	0.04%	4
BabR2005	Welfare	-0.41%	(-0.41% -0.41%%)	-0.41%	0.00%	1	-0.41%	(-0.32% -0.32%)	-0.32%	0.00%	1